Director and State Geologist Thomas A. Drean

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Ti TD (Rt1_1 1 Tf 12 0 0 12 474.996 509.9955 Tm (15)Tj -30.583 -1.2 Td [(B)6(ear . . . .

Tables

ABSTRACT
Rare earth elements (REE) comprise a group of metals with similar physical and chemical proper-

Survey (WSGS) compiled an Open File Report on REE and yttrium in Wyoming in 1987, which was updated in 1991 and again in 2002 (King and Harris, 1987; King, 1991; King and Harris, 2002). However, these reports were based on literature searches and did not include any original sampling or analyses.

Between 2009 and 2012, the WSGS began to sample and analyze potential REE host rocks within the state. Using WSGS Open File Report 91-3 (King and Harris, 2002) as a foundation, the WSGS compiled data from existing sources, collected and analyzed a small number of new samples, and re-analyzed some samples collected at earlier dates.

In March of 2012, the Wyoming State Legislature allocated $200,000 of Abandoned Mine Lands Reclamation (AML) funds to the WSGS to conduct a geological and geochemical investigation on potential REE-bearing, as well as other potentially economic deposits in Wyoming, cataloging those deposits, and providing a report on the ndings on REE and is to the foliter sads o

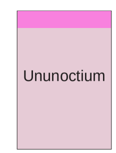

Table 1. Periodic Table of the Elements with REE outlined in black. (Chart by James R. Rodgers, Wyoming State Geological Survey.)

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about 0.34 percent, and 10,000 ppm would be about 1.15 percent TREO.

Total REE values greater than 3,000 ppm may be ability and economic factors, including su cient deposit size and tenor, consistency of ore grades, uniform mineralogy, favorable chemistry for metal extraction, mine siting, transportation, etc.

In contrast to base metals (such as coppsr, lead, or iron) and precious metals, REE have very little tendency to become concentrated in exploitable ore deposits (Haxel and others, 2002). LREE are more incompatible because they have larger ionic radii and are therefore more strongly concentrated in the continental crust than HREE. In most rare earth deposits, lanthanum, cerium, praseodymium, and neodymium constitute 80 to 99 psrcent of the total. Because of this, deposits containing relatively high grades of the less common and more valu-able HREE (gadolinium to lutetium, ytt ceriuand europcer) are particularly desirable.

REE Uses

Table 3: Lanthanum oxide additiv8T1_e in opt_0 1Glenlemoincrealemolight refraction8(58.7]TJ Edecrealemodisp7moion, ca

Slow economic conditions worldwide during 2012, combined with more e cient material usage, resulted in a decline in United States REE imports from 7,790 tons in 2011 to 5,700 tons in 2012. e economic slowdown also resulted in a decline in prices for most REE products in the aftermath of signiton5cant price increases during 2011. e value of reton5ned REE imported by the United States decreased from $802 million in 2011 to $615 million in 2012 (U.S. Geological Survey, 2013).

e largest known REE deposits occur in China, Australia, and North America, with much smaller reserves found in India, Brazil, Malaysia and South Africa. Production has beeTepooEoated by China, with additional production from Australia, India, Malaysia, Russia, and ailand (Hedrick, 2004). China's reserves are the largest. Estimates project that China has the largest percentage of worldwide REE reserves at about 36 percent, compared to the United States at about 13 percent (Long, Van

Extraction of REE

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considered an impediment to mining and processing. Because of this, world monazite production is relatively small (Hedrick, 2004).

Monazite forms translucent, brownish-red to yellow, equant to tabular prismatic crystals with wedge-shaped terminations and a vitreous to adamantine luster. It has a good planar cleavage, a conchoidal fracture, and may be found in both granular and massive forms. Metamict alteration due to radioactive decay of thorium is usually present in monazite and shifts its luster to resin-

REE deposit in Wyoming and is currently well-advanced in exploration, including metallurgical and environmental studies directed toward mine development (Rare Element Resources, 2013a).

Exploration in other parts of Wyoming that eventually resulted in identi cation of REE or REE-bearing minerals similarly focused rst on uranium and thorium. Paleoplacers in the Bald Mountain area of the Bighorn Mountains were rst exa 0 -1sJ Tr lwa-grade goldin the Blattr phalf

All samples analyzed for this study are shown in gure 1. is gure also shows samples with greater than ve times average continental crustal abundance of one or more REE. ese occurrences do not imply economic deposits. However, they do

located on Carbon Hill and on the west ank of Bull Hill (Rare Element Resources, 2011).

Carbonatite is mostly calcite, but may also contain accessory minerals commonly associated with REE-enaccessory aegirine, apatite, strontianite, barite, and celestite (Rare Element Resources, 2011).

LREE dominate the Bear Lodge deposit. However, a press release by Rare Element Resources on August 4, 2011 describes high HREE grades in the northern and western portion of their project area. These localities are referred to as their White-

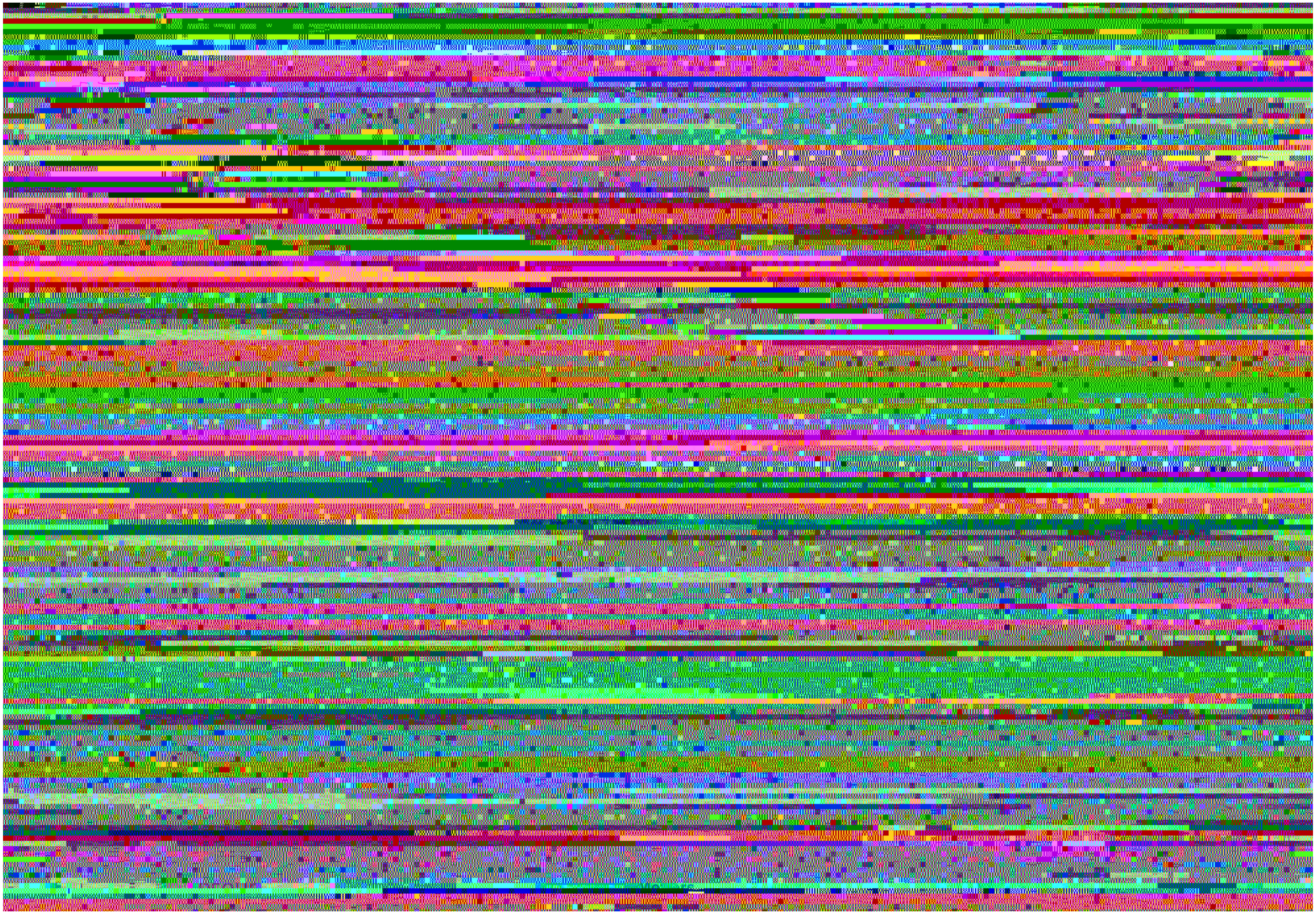

Figure 3. Map of the Rare Element Resources, Ltd. Bear Lodge Project area. (John Ray, Rare Element Resources, Inc.,

Precambrian O

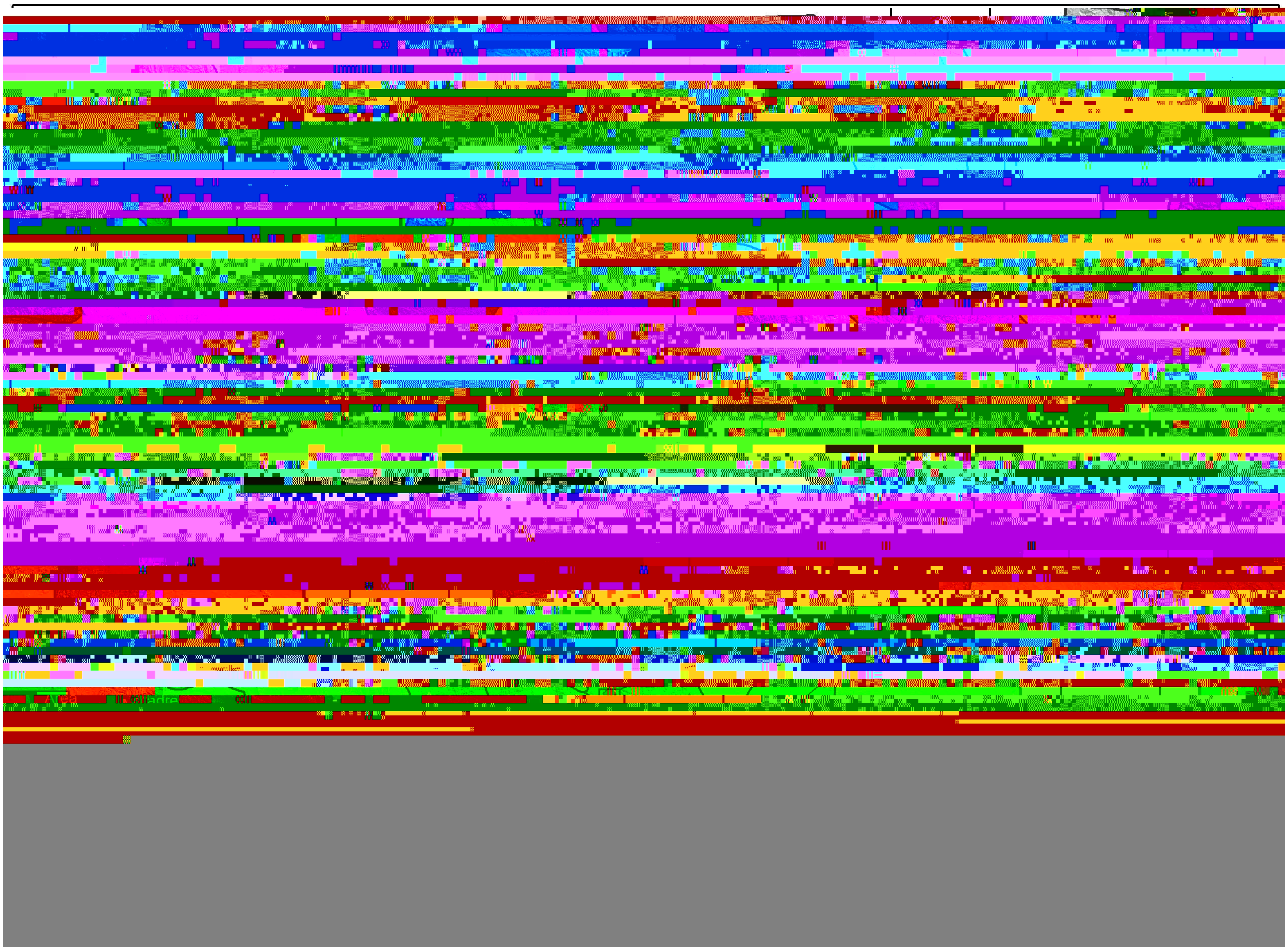

Figure 4.

the Tie Siding pegmatites. e altered pegmatite

coarse-grained granite (QAP: 30% Q, 40% A, 30% P) at this location is weakly enriched in some of the HREE (Sample g0120921BG-7).

Big Creek D

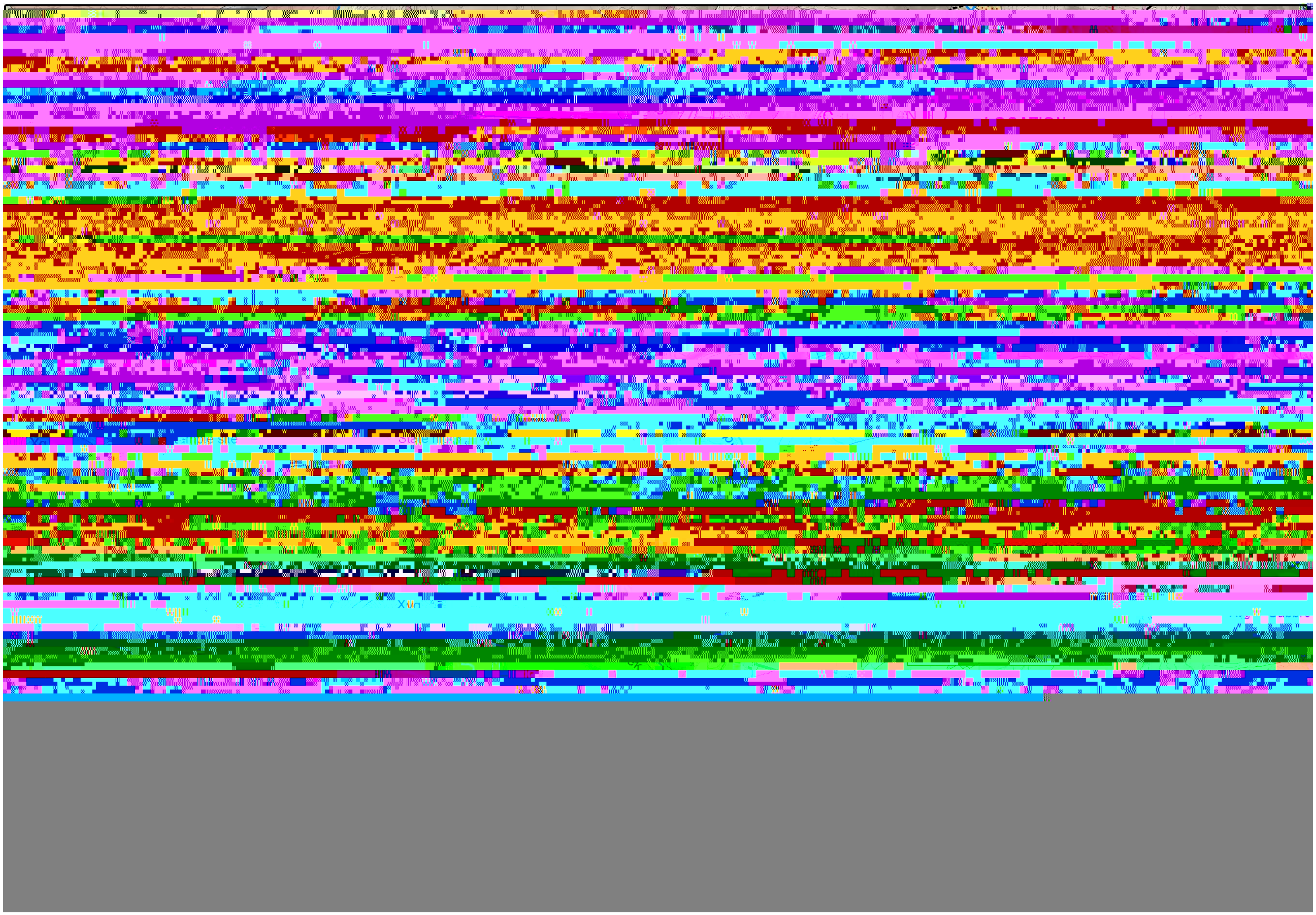

Figure 8. Sample locau249os and geology of the B12(aig C)6(r)1(e ek pegmu24tr(D)sE) ct, modi ed fromSutherland and Hausel (2005)

lbs) for 1957 and 450 kg (1,000 lbs) for 1958 (King and Harris, 2002).

e euxenite was reported by Houston (1961) to be metamict to the extent that it gave no x-ray dif-

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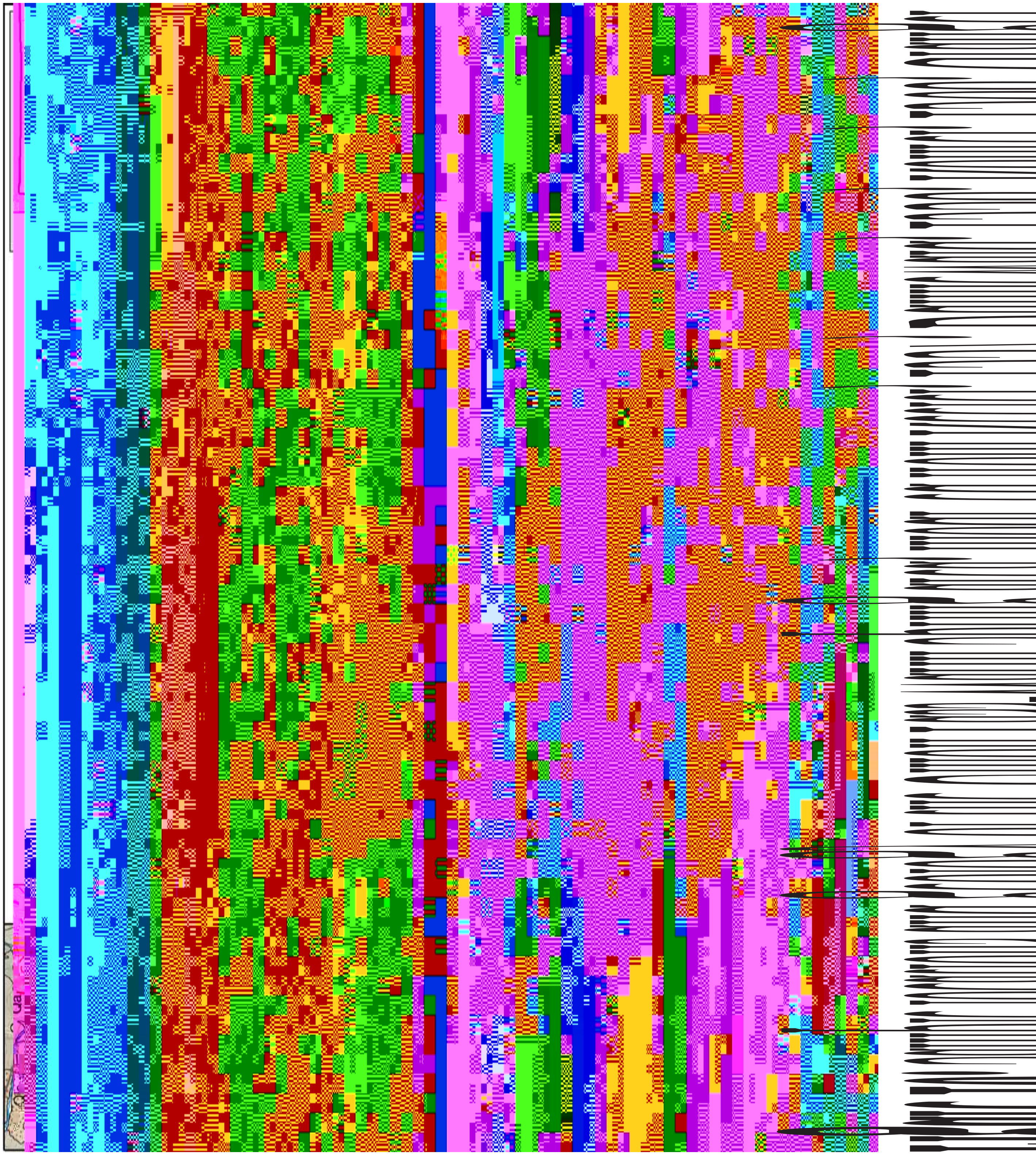
Several pegmatites occur in the N½NE¼ sec. 8, T. 13 N., R. 81 W. (Houston, 1961). One of these was discussed in a 1982 DOE National Uranium Resource Evaluation report (NURE) (Dribus and Nanna, 1982). e report identi ed a 30- to 91-cm (1- to 3-ft) wide, 30°-trending garnet-bearing granite pegmatite that cut Early Proterozoic biotite schist. e pegmatite exhibited two to 17 times background radioactivity (Geslin, 1954; Dribus and Nanna, 1982), and contained black, metallic minerals identi ed as euxenite and allanite with the use of Scanning Electron Microscope-Energy Dispersive Spectroscopy (SEM-EDS). Various early analyses reported up to 0.1 percent uranium (King and Harris, 2002). No REE analysis is known from this location.

A similar pegmatite dike in the S½ sec. 13, T. 13 N., R. 81 W., cuts granitic gneiss near its contact 1961). OSutherland and Hausel, 2005). ospect pit and in outcrop. e dike is granite pegmatite with abundant biotite and hematite, moderate garnet granite to granodiorite with rapakivi texture,as0 32ts



pyroxenes and olivine. Iron-rich oat is present along the length of the lineament. Ullmer (1983) argues that the iron-rich composition and mineral assemblage of the relatively unaltered rocks at the northwest end of the lineament suggest that the iron-rich pods are metamorphosed iron formation, rather

Dubois claims is associated with the emplacement of granitic dikes. e unaltered radioactive granite is weakly enriched in the LREE, as well as gadolinium and terbium. e altered granite and the iron-rich pod exhibit no notable enrichment (table 10).

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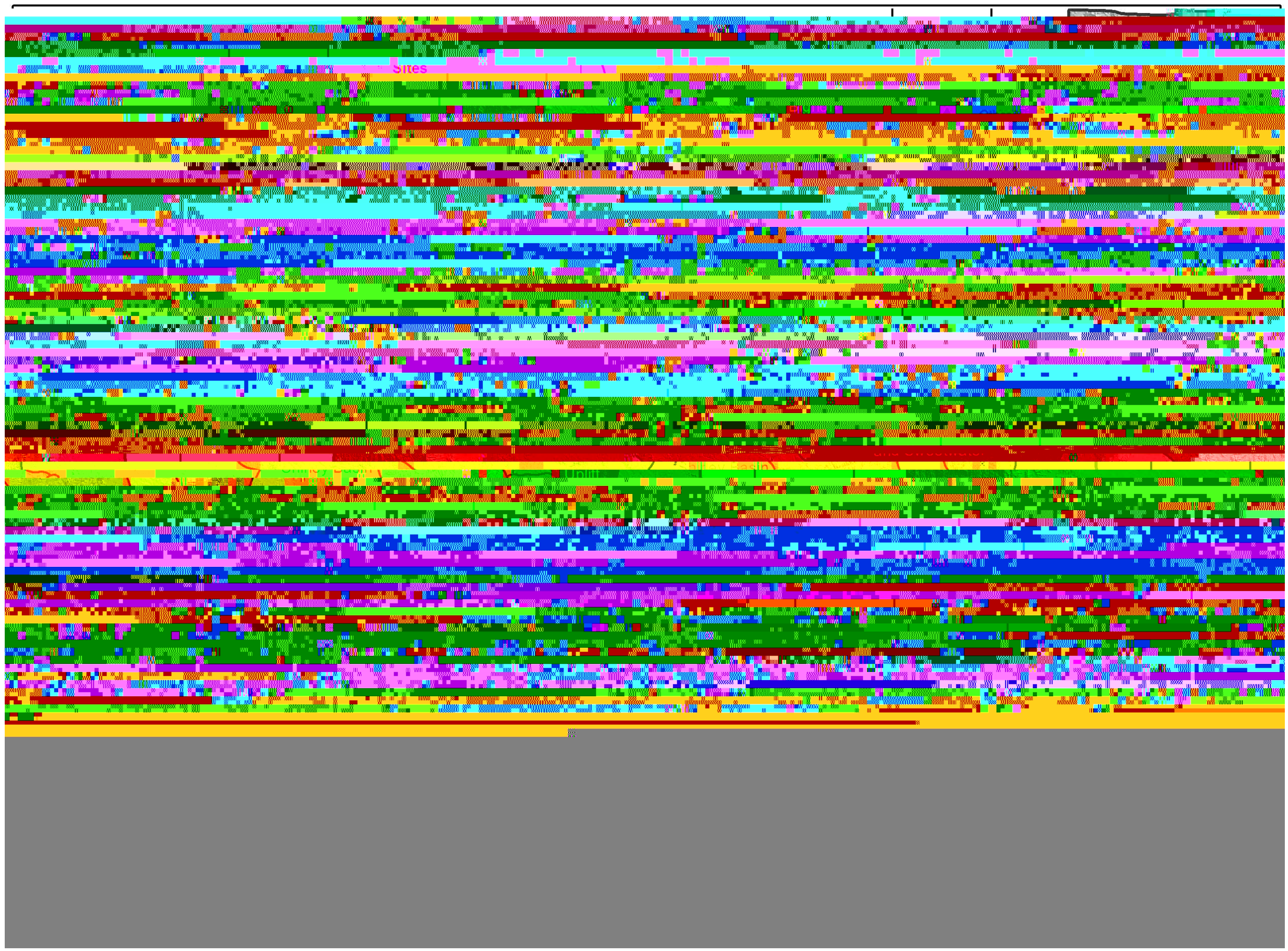
Ullmer (1983) reported that uranium mineralization (up to 2.4 percent U_3O_8) in this area is hosted in a brittle deformation zone within an altered magnetite- and biotite-rich pod in Archean gneiss. e ndings of Ullmer (1983) are in agreement with Granger and others (1971), who found pitchblende within a quartz-, hematite-, and magnetite-cemented breccia zone cutting biotite gneiss. Ullmer (1983) interprets the magnetite- and ported a sample analysis from this dike of 700 ppm La, 100 ppm Y, 200 ppm Zr, 114 ppm eU, and 70 ppm e 1.2 T0z3Teidosite sample (20121023WS-B) showed enrichment at greateg.6ite. tGS0e times crustal abundance in all of the naturally occurring LREE and gadolinium, and weak to moderate enrichment in the remaining HREE, except for yttegbium (table 11). King and Harris (2002) noted that similar dikes are present in the surrounding areas in Carbon, Fremont, and Natrona counties.

Babbs Mine, E¼ sec. 26, T. 27



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downstream from older REE mineral concentrations.

Flathead Sandstone Paleoplacers

e Middle Cambrian Flathead Sandstone, referred to by some early workers as the Deadwood Conglomerate, is the oldest sedimentary formation above the Precambrian in Wyoming and has a maximum thickness of about 170 m (560 ft) (Kanizay, 1978). Figure 13 shows the locations of WSGS samples collected from the Flathead Sandstone. e Flathead is dominantly quartz-rich, subangular, medium- to coarse-grained sandstone with large-scale cross-bedding. Non-quartz grains include abundant feldspar and crystalline lithic fragments typical of the underlying granite. Most of the formation is thin- to thick-bedded and well-cemented with a predominant reddish-brown color that grades to purple, rusty-orange, yellow, or gray. e sandstone is interrupted by thin layers of greenish-gray siltstone and shale, particularly in the upper part of the formation. e Flathead represents a uvial-marine transition zone along a north-south oriented shoreline with braided stream

Precambrian rocks in the Bald Mountain area are not known to host signi cant precious metal deposits. However gold paleoplacers within the

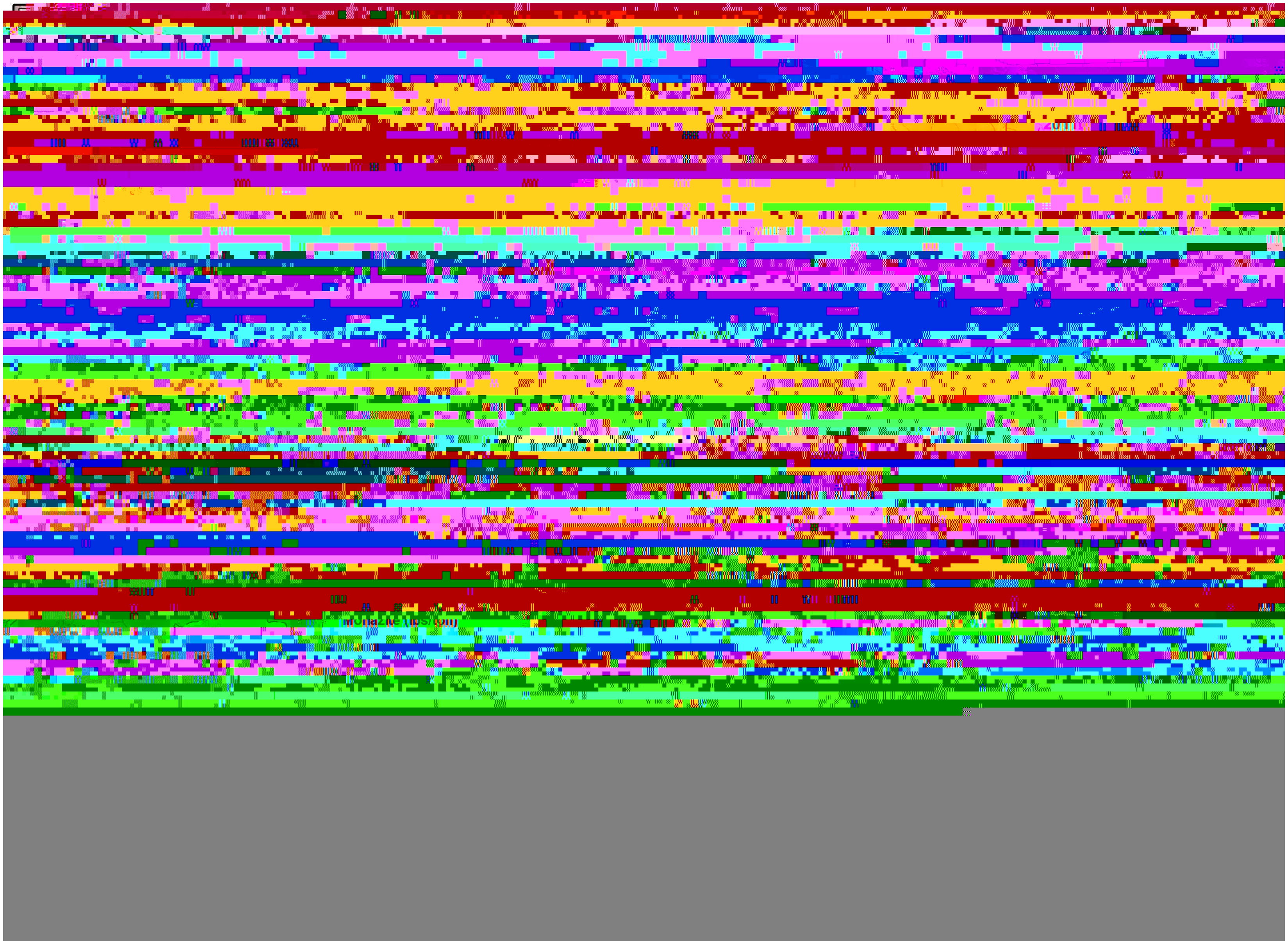

Figure 15. Locations of 1952 USBM drill holes and WSGS Bald Mountain and Rooster Hill samples. Drill data shows maximum grades in pounds of monazite per ton, after McKinney and Horst, 1953. WSGS samples show total REE in ppm. Blue numbers indicate greater than ve times average crustal ppm values. Geology modi ed from Cardinal (1958) and Love and Christiansen (1985).

content of that mineral." Apparently the USBM and AEC were also concerned with the availability of REE in 1953 in addition to thorium.

No published analyses for REE are known for the Bald Mountain area prior to WSGS investigations. However, assuming typical values for monazite concentrates of about 61 percent REO (Long, Van Gosen, Foley, and Cordier, 2010), the average for the estimated Bald Mountain paleoplacer resource as reported by McKinney and Horst (1953) would be 0.7630 kg REO/tonne (1.525 lbs REO/ton) or 0.076 percent REO. e high-grade paleoplacer material would be around 4.02 kg REO/tonne (8.05 lbs REO/ton) or 0.40 percent REO.

King and Harris (2002) argue that the resource interpretations for the paleoplacers in the Bald Mountain area were made with the assumption of a relatively uniform, sheet-like zone of monazite enrichment in the lower Flathead beach deposits. However, the more erratic braided stream depositional environment, now believed to host most of the monazite, suggests that these numbers may be less accurate than originally believed (King and Harris02). e weakly indurated character of this paleoplacer may have some economic advantage over hard rock deposits with similar REE grades. in overburden and the potential for easy disaggregation and gravity concentration of high-grade material prior to shipping should be considered in any evaluation.

In 2011, ve samples were collected by the WSGS from east of Rooster Hill and three from the west end of Bald Mountain. Samples 20110824WS-C, 20110824WS-D, and 20110824WS-F showed significant REE with total REE contents of 4,714.68 ppm, 6,815.69 ppm, and 2,309 ppm respectively (table 14). ese samples were high in most LREE and showed elevated values for HREE and yttrium. ey were also signi cantly high in thorium, and samples 20110824WS-C and 20110824WS-D were high in uranium. Some of the other samples showed slightly elevated LREE values, but they did not exceed ve times average crustal abundances.

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e Flathead S andstone in this area contains up to 134 ppm thorium, but less than 5 ppm uranium, and is likely a typical Flathead S andstone paleo-placer (M alan, 1972). e Flathead here consists of white to red, quartz pebble conglomerate and medium- to coarse-grained, poorly sorted, sub-rounded, iron-rich subarkose, with coarse weathtourmaline, amphibole, spinel, sphene, epidote, biotite, chlorite, staurolite, and apatite. Zircon and garnet are the most abundant of the translucent heavy minerals (Houston and Murphy, 1962). Analyses of samples collected by the WSGS from the Mesaverde Formation in Wyoming are presented in table 16.

Separation Rim, SE¼NW¼ sec. 22, T. 24 N., R. 89 W., Northwestern Carbon County

A black to dark brown, ne-grained, iron-stained sandstone crops out along the ridge of a Mesaverde Formation hogback in the Separation Rim quadrangle. A sample of this black sandstone (Sample 20120730WS-A) exhibits no enrichment of REE or any other element of economic interest. is black sandstone had not been previously inf economic interest. is

Cottonwoor Creek, SE¼SE¼ sec. 26 anr NE¼NE¼ sec 35, T. 45 N., R. 97 Norther Springs County

e titaniferous black sanrstone in the Mesaverde Formation at Cottonwoor Creek is a dark brown to black anr rusty-brown, ne- to medium-

percent ma c minerals, 25 percent limonite, 20 percent weathered plagioclase, 10 percent quartz, 5 percent black opaque minerals, and calcite fracture lls (Sample 20121128JC-D). In places, the ma c minerals in the upper portior of the exposure appear to have gro around plagioclase. Background radioactivity in the area is 907 [(to y)6(elp.mnt ma c

ppm niobium, and 660 ppm e within altered sandstone in the Cretaceous Frontier Formatior. is sandstone exhibits a mineralogical assemblage typical of beach placer deposits and contains limonite, pyrite, leucoxene, and an unidenti ed REE-bearing mineral. e stratigraphy of samples reported by Madsen and Reinhart (1982) is ambiguous (King and Harris, 2002). Recent mapping (M'Gonigle and Dover, 2004) and eld investigatiors from this study show that this sandstone is within the lower third of the Frontier Formatior (gs. 19 and 20).

An exploratior trench near the area sampled by Madsen and Reinhart (1982), exposes light green to yelhe loweathered), angular to subangular, medium- to coarse-grained sandstone, with approximately 25 percent weathered plagioclase, 40 percent quartz, 35 percent ma c minerals, 5 percent biotite, and minor limonite and hematite staining (Sample 20121128JC-E). is weathered sandstone unit is overlain by a dark green to dark bro, medium- to coarse-grained laminated sandstone (g. 19) with approximately 40

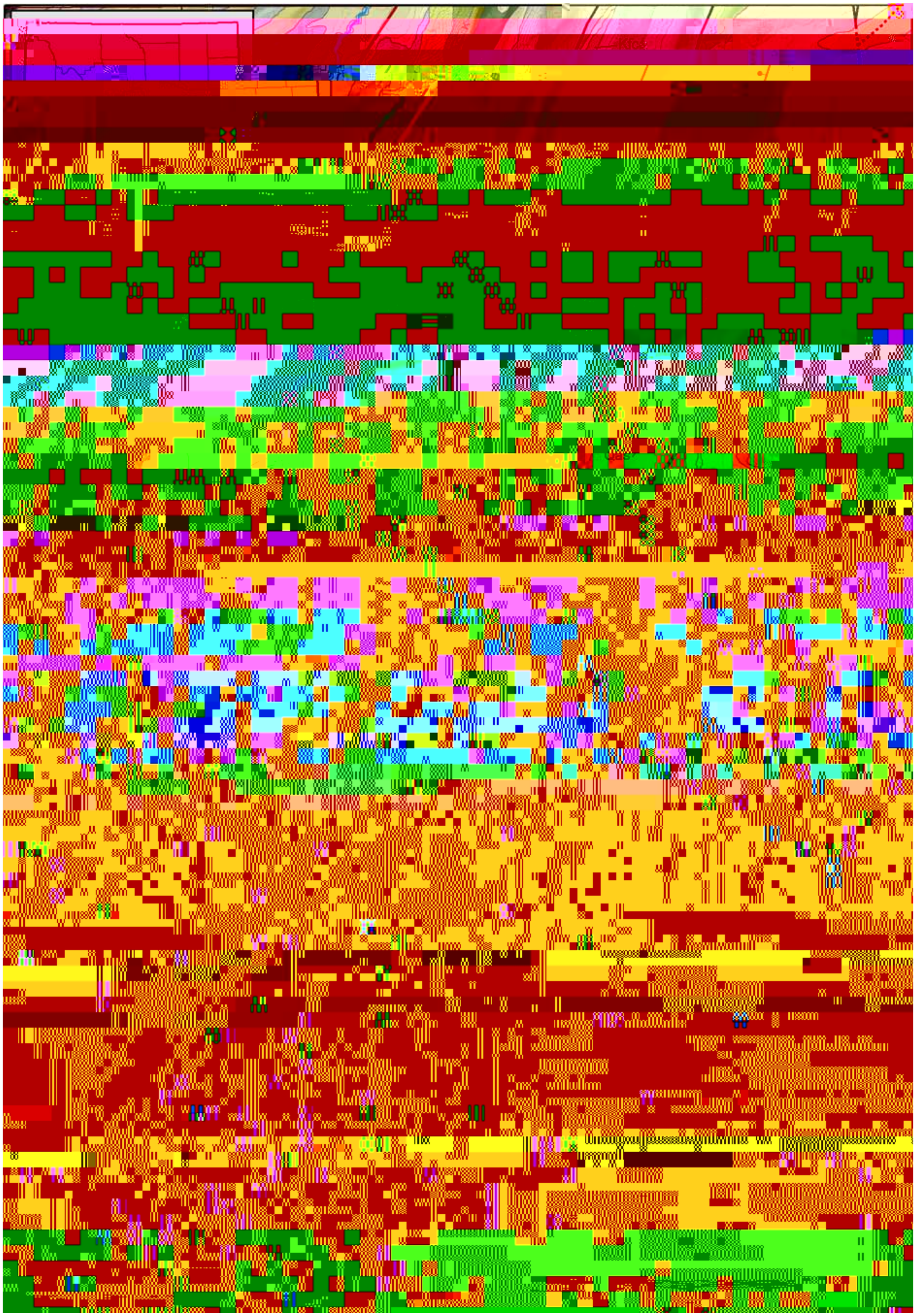
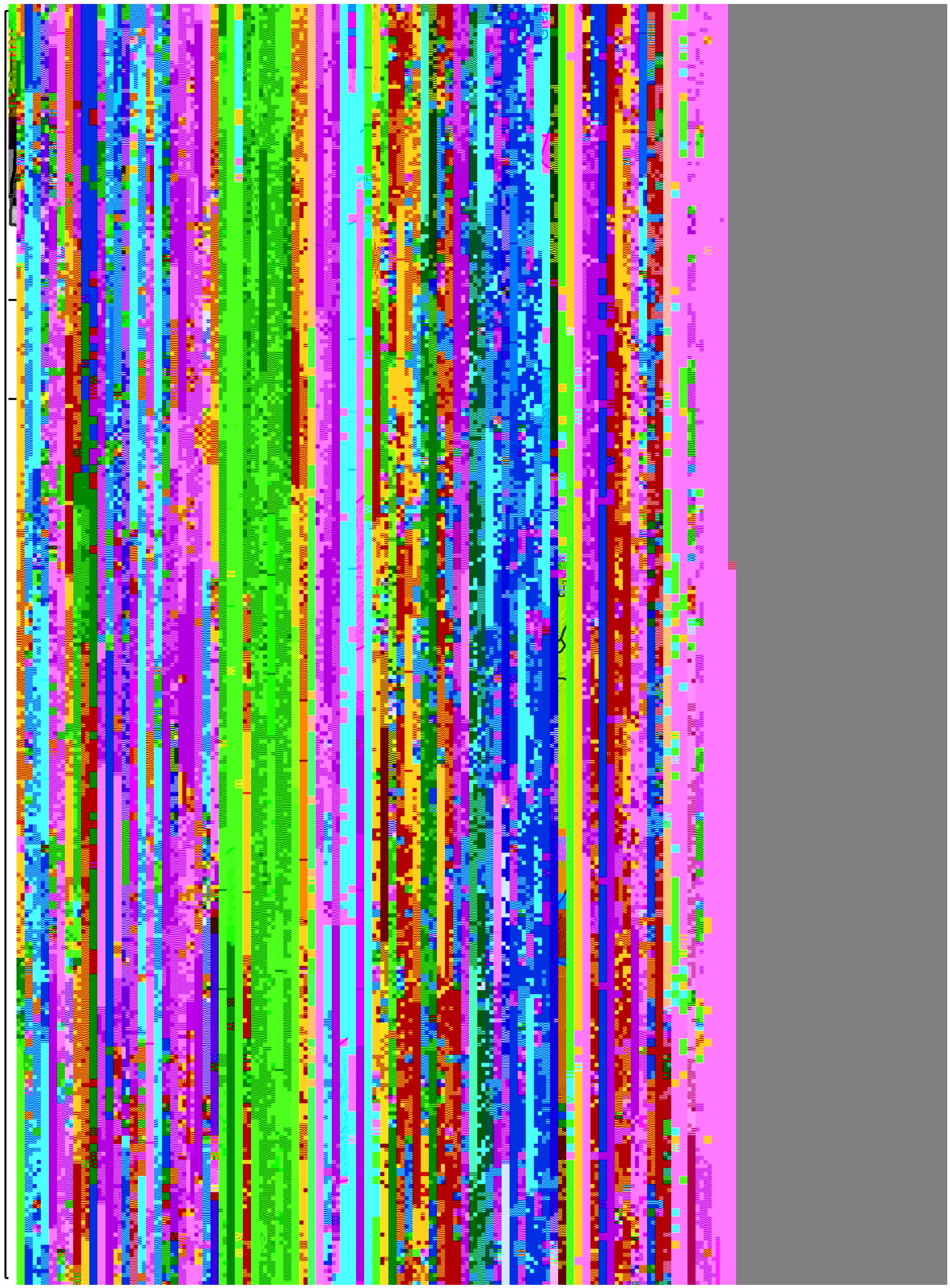


Figure 20. Sample locations and geology of the Spring Gap area, Uinta County, modi ed from M'Gonigle and Dover (2004).

interaction between oxidized groundwater and reduced geologic environments. Such deposits are known sources of uranium (e.g., Smith Ranch mine, Wyoming) and a silver and copper (e.g., Paoli deposit in Oklahoma; Thomas and others, 1991). These geological environments potentially host other metals as well.

Deacon's Prayer Group Claims, SE¼SE¼ sec. 18, T. 32 N., R. 82 W., Southern Natrona County

Griffin and Milton (1982) reported 90 ppm cU_3O_8, 250 ppm lanthanum, 70 ppm yttrium, 3,000 ppm titanium, and 300 ppm zirconium within a coarse-grained to conglomeratic arkosic



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distinct horizons (plus one unit within the underlying Tipton Shale Member), and four uraniferous phosphatic zones (UPZs) in the NE¼SW¼ sec. 10, T. 17 N., R. 106 W. (table 19). e UPZs in the lower part of the Wilkins Peak tend to be more enriched in uranium and phosphate (up to 0.15

entirely on descriptions of eld relations provided by Love (1964).

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Mudstone and limestone of the Wilkins Peak

1977; Love, 1984). REE concentrations are typically correlated with phosphorus content, due to an association with apatite. Despite its promise as a host of REE, the Phosphoria Formation has been the subject of few REE analyses (King and Harris, 2002).

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e Phosphoria Formation crops out along US 89, near the historic town site of Hoback, in extensively folded and faulted terrain, and was the target of a phosphate exploration trench (Albee, 1968). e Phosphoria overlies the Mississippian and Pennsylvanian Wells Formation and is overlain by the Triassic Dinwoody Formation. e northeastern margin of this outcrop is cut by a high-angle fault that places the Phosphoria Formation in fault contact with the Wells Formation (Albee, 1968). e

Dahllite Concretions in the

e Gold Coin mine targeted copper, lead, gold, and silver mineralization within a 0.3 m (1.0 ft) wide quartz vein (Beeler, 1902; Hausel, 1997). e vein is concentrated within a ssure that trends 75° and dips to the south at a high angle (Spencer, 1904). e vein cuts the regional foliation of the hosting Late Archean black diorite (Beeler, 1902; Spencer, 1904). A sample of vein quartz with abundant limonite (possibly replacing sul des), galena, chalcopyrite with chalcocite rims, and minor malachite (Sample 20121203WSGS-B) from the Gold Coin mine yielded 318 ppm (9.27 oz/ton) silver, 0.11 ppm (0.003 oz/ton) gold, 0.11 percent copper, and 14.6 percent zinc.

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e Section 8 mine targeted copper mineralization hosted in pyritized banded chert within amphibolite of the Silver Lake Metavolcanics, though the exact eld relationship between the amphibolite and chert is unknown. In addition to the amphibolite, chlorite garnet schist is also present in the Silver Lake Metavolcanics in the vicinity of the Section 8 mine. e banded chert has a trend of 81° and dips 52° SE. Mineralization is concordant with the local banding in the chert. A sample from the mine yielded 2.61 percent copper but no detectable gold (Hausel, 19e6; 1997); no silver was reported. A sample of pyrite- and chalcopyrite-bearing banded chert (Sample 20121203WSGS-D) yielded 27.4 ppm (0.80 oz/ton) silver and 6.75 percent copper.

stained vein quartz, mineralized with chalcopyrite, pyrite, bornite, malachite, and hematite, analyzed for this report yielded 17.25 ppm (0.50 oz/ton) gold, 41.3 ppm (1.20 oz/ton) silver, and 2.62 percent copper.

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e Black Rock Gap prospect is located along

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Notes

Results from this Mineral Investigation include the raw analytical data in an appendix.

Wyoming Database of Geology —
Analyses, write-ups, and photographs
of REE and other samples.

www.wsgs.uwyo.edu/research/minerals/Rare-Earths.aspx

Geology — Interpreting the past – providing for the future